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Technical Report ARFSD-TR-92024

INTRODUCTION TO LEAD SALT INFRARED DETECTORS

David A. Kondas



93-02184



2084

February 1993



US ARMY
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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operation and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE February 1993		3. REPORT TYPE AND DATES COVERED 9/90-9/92
4. TITLE AND SUBTITLE INTRODUCTION TO LEAD SALT INFRARED DETECTORS			5. FUNDING NUMBERS	
6. AUTHOR(S) David A. Kondas				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES(S) ARDEC, FSAC Precision Munitions Div (SMCAR-FSP-E) Picatinny Arsenal, NJ 07806-5000			8. PERFORMING ORGANIZATION REPORT NUMBER Technical Report ARFSD-TR-92024	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(S) ARDEC, IMD STINFO Br (SMCAR-IMI-I) Picatinny Arsenal, NJ 07806-5000			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This technical report establishes the background necessary to understand how lead sulfide (PbS) and lead selenide (PbSe) infrared detectors operate. Both detectors, which are members of the lead salt family of infrared detectors, use the photoconductive effect to detect energy residing within the infrared region of the electromagnetic spectrum. PbS detectors are useful for detecting energies in the 1 to 3 micrometer region, while PbSe detectors can detect energies in the 1 to 7 micrometer region. They are essentially polycrystalline thin films which are fabricated by chemical deposition techniques in either single element or multi-element array configurations. The significance of the electronic structure of these crystalline films and the effects of temperature on their operation and performance are discussed. The history of the development of lead salt detectors from the early years before World War I to the more recent developments is detailed. In addition, an overview of a typical infrared system is also presented.				
14. SUBJECT TERMS Lead sulfide, Lead selenide, Photoconductivity, Semiconductor thin films			15. NUMBER OF PAGES 24	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

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INTRODUCTION

The foundation for the research and development of infrared detectors began with the discovery of the infrared portion of the electromagnetic spectrum in 1800 by the English astronomer Sir William Herschel (1738 - 1822). Herschel, already famous for his discovery of the planet Uranus, was attempting to find a method for protecting his eyes when viewing the sun when his experiment led him to the discovery that radiant energy existed beyond the visible spectrum. While using a prism to spread sunlight into its various wavelengths, he used a thermometer to measure the temperature at various locations on which different portions of the spectrum fell (ref. 1). He observed that the thermometer indicated a significant amount of heat existed in those areas where he could not see any color. Since any object at any temperature above absolute zero emits electromagnetic radiation, it became apparent that an infrared detector could be used to sense the presence of objects in situations where they could not be seen with the naked human eye. Herschel's efforts soon resulted in the development of Golay cells, bolometers and thermopiles. These were some of the earliest infrared thermal detectors that were used to sense temperature changes. By the end of World War I, research was being conducted on various lead salt materials for infrared detection and communications applications. These were photon detectors that responded to the transfer of infrared energy from incoming photons to electrons residing within the detector material resulting in a change in the conductivity of the device. However, it wasn't until the 1930s that a prolific amount of research was conducted in Germany on lead salt infrared detectors for military applications. Eventually, the United States became involved in the study of these detectors for similar reasons. Even today, despite a decline in the amount of research into the behavior of lead salt detectors, the two detectors that offer some of the greatest applications to military, commercial and medical applications are lead sulfide (PbS) and lead selenide (PbSe).

Infrared detectors are generally classified as being either thermal or photon (quantum) detectors. Among the photon detectors there are two major types: photoconductors and photovoltaics (ref. 1). As shown in figure 1 on page 2, PbS and PbSe detectors are both members of the lead salt family of photoconductive infrared detectors. Photoconductive detectors are thin film semiconductor devices which undergo a change in conductivity when exposed to varying quantities of radiation. In the case of both detectors, incident photons in the infrared region bombard the surface of the thin film semiconductor and collide with electrons residing within the valence band of the detector material. This interaction stimulates the generation of electron-hole pairs. Consequently, this results in an increase in the amount of current flowing through the device. The output signal of the detector circuit is either a change in detector current or a change in voltage developed across a load resistor. Thus, when the device is incorporated as part of a sensor system, it is these current or voltage changes which are interpreted by the detector circuit processor as being the target of interest or not.

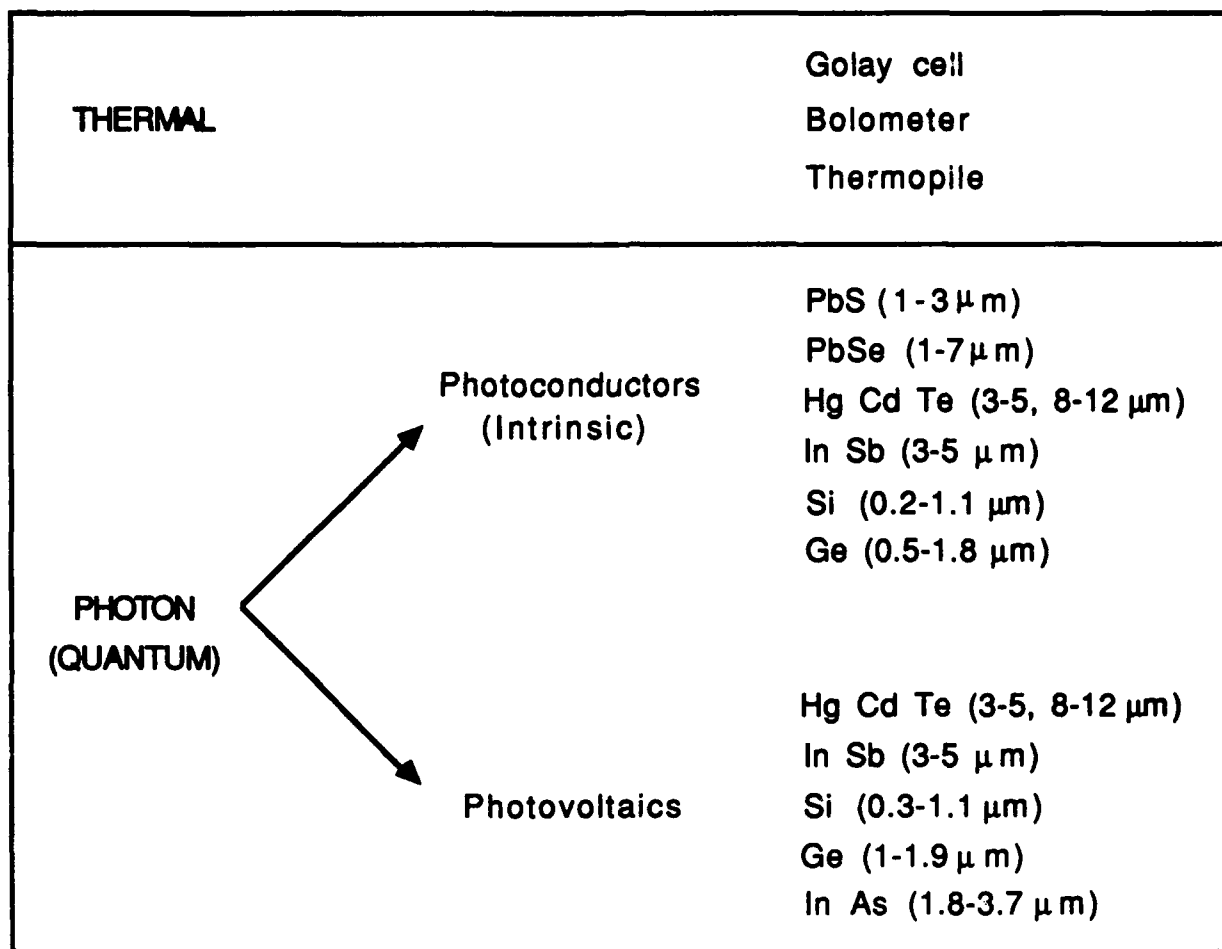


Figure 1. Types of infrared detectors (ref. 1)

The structure of a lead salt infrared detector is that of a thin film semiconductor. These thin films are polycrystalline in nature, with individual PbS crystals ranging in size from 0.1 μm to approximately 1.0 μm in diameter, and PbSe crystals ranging in size from 0.2 μm to 0.8 μm in diameter (ref. 2). Lead salt detectors are manufactured as either single element detectors or multi-element detector arrays, the latter for which there are several array designs. A single element detector, which usually possesses the geometry of a thin plate, is shown in figure 2 on page 3. The fabrication and basic structure of both of these detector configurations have many similarities. Both configurations utilize chemical deposition techniques to precipitate photosensitive thin films on a flat, cylindrical or spherical substrate surface. However, the most widely used fabrication method is to chemically deposit a lead salt solution onto a flat surface substrate. The major differences between single element detectors and detector arrays are the overall detector sizes, patterns and overall complexity.

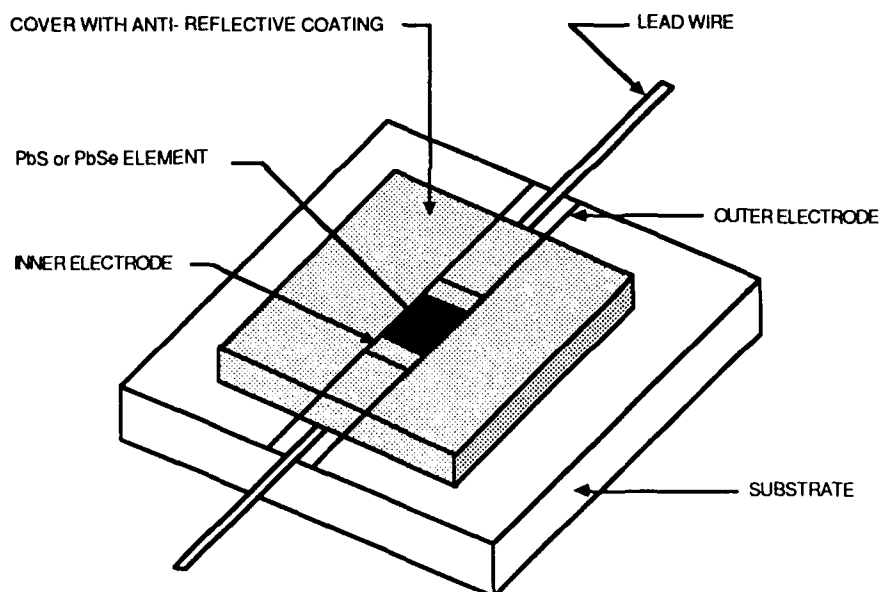


Figure 2. A single element lead salt detector (ref. 2)

Due to the strategic importance of the application of lead salt detectors for some of the military's current smart weapons programs, as well as the many significant commercial and medical uses, there is a need for those involved in each field to be made more knowledgeable about the behavior and operation of these semiconductor devices. Therefore, the primary purpose of this report is to establish the technical background necessary to understand how PbS and PbSe detectors function. This report initially details the historical development of lead salt detectors from the early years before World War I to the more recent developments. This is followed by a section which discusses the infrared detection process on an atomic level, followed by a section which describes the operation of a typical infrared detector system.

This report is the first in a series of three reports written by the author which together are intended to provide a comprehensive overview of lead salt infrared detectors that are being used for military, commercial and medical applications. The second report focuses on the structure and fabrication of both PbS and PbSe detectors, while the third report addresses the issue of detector performance and presents many military, commercial and medical uses. It is the intent of the author to present the material within this report in such a manner so as to provide somewhat of a general understanding of the phenomenon of photoconductivity and the system operation of lead salt infrared detectors. Since an in-depth approach to the treatment of this material would require the reader to possess a thorough background in the areas of thermal radiation and solid state physics, the author has chosen to discuss the fundamental concepts of lead salt detectors with respect to the aforementioned topics.

THE HISTORY OF LEAD SALT DETECTORS

Intensive investigations into the use of lead salts for detecting infrared radiation occurred during a ten year period ending around World War I. Research efforts performed during this time were concentrated into studying material behavior rather than achieving more sensitive devices. Prior to this period, a notable amount of time had been spent attempting to find applications for lead salt crystal cells. It wasn't until the early 1930s that successful methods to develop thin films of lead salts were achieved in Europe. Knowledge that lead salt detectors were being used for military purposes by Germany during the middle of World War II forced the United States to start its own research efforts. Further development of these devices over the years since then were driven by military demands. Even today, despite having many commercial applications, lead salt detectors are primarily used to satisfy military needs.

Pre-World War II Development

The earliest efforts leading to the development of lead salt detectors actually began in 1873 when Willoughby Smith first observed and recorded the photoconductive effect, the primary mechanism responsible for the operation of lead salt detectors. Smith was investigating the use of selenium, a nonmetallic element resembling sulfur, as an insulator for undersea cables (ref. 3). Smith had observed that selenium offered less resistance to the flow of electricity when exposed to light than when it was kept in the dark. Since it soon became known that the spectral response of selenium extended into the infrared region of the electromagnetic spectrum, scientists curiously began conducting experiments using selenium cells for investigations that required an infrared sensitivity. However, these experiments did not produce any significant results that would identify immediate applications. Thus, it wasn't until 1916 that Theodore Case, continuing the earlier work of Smith, began a lengthy investigation into the behavior of over 200 salt compound crystals for changes in resistance when exposed to light in the infrared region of the electromagnetic energy spectrum (ref. 3). His conclusion was that most of the light reactive crystals were found to be sulfides, with bismuth sulfide and a granular lead antimony sulfide exhibiting rather excellent characteristics. Case was hoping to develop a signaling device for a communication system that would use infrared radiation, thereby making it invisible. He was successful in developing a communication system that would transmit signals over a distance of 18 miles using a thallium sulfide cell as a receiver. The "Thalofide" cell was nothing more than a quartz disc upon which was melted a layer of thallium sulfide (ref. 3). However, his efforts were not considered a complete success due to the fact that the cell suffered fatigue when exposed to short wavelengths, as well as the fact that it could not be manufactured in such a manner that would yield results which were reproducible. Consequently, since there was little interest for further development immediately after World War I, work in the area virtually ceased.

Subsequently, intensive efforts began in Germany during the early 1930s to develop thin films of lead salts, with much of the early effort primarily dedicated towards PbS films. It was during this time that Edgar W. Kutzscher, of the Department of Physics at the University of Berlin, discovered that PbS crystals could be fabricated that would exhibit an excellent short wavelength sensitivity superior to any other known detectors available (ref. 3). Kutzscher basically connected several crystals in series to make a PbS cell that could achieve results similar to bolometers that were in use at that time. His early research efforts were supported by the German army. Consequently, his work led to the production of PbS passive infrared detectors that were used to detect aircraft and ships along the European coast. By the middle of World War II, photoconductivity was finally observed in PbSe at liquid nitrogen temperatures in Germany (ref. 4). The emergence of PbSe for use in fabricating infrared detectors began as the result of a desire to extend the spectral range of PbS detectors at that time. It was also at this time that methods were being developed in both England and Germany to achieve sensitive thin films of lead salts that would exhibit photoconductive behavior at longer wavelengths. British scientists soon reported results obtained at room temperature, as well as at liquid nitrogen temperatures, that revealed a drop in the spectral response curves at about 5 μm , as opposed to reports of drops at about 3.3 μm (ref. 3). Subsequent research indicated that PbSe would help expand the 1 μm to 3 μm region covered by PbS to the 1 μm to 7 μm region. As a result, the combination of both lead salt detectors had thus made it possible to detect infrared energy within the 1 μm to 7 μm range of the electromagnetic spectrum. Eventually, the British dedicated a great deal of effort towards achieving a better comprehension of the behavior of these semiconductor thin films. Despite the fact that some effort was made to achieve better fabrication techniques, most of the effort towards the end of World War II was still dedicated to finding military applications for lead salt films.

Meanwhile, knowledge of the advancement of lead salt detectors for military purposes in Europe forced the United States to form the National Defense Research Committee (NDRC) in June 1940. As a result, Robert J. Cashman of Northwestern University was hired by the NDRC to pioneer research efforts into the development of infrared sensitive cells. In 1941, Cashman resurrected the efforts of Case and began extensive research into improving the characteristics of thallous sulfide films. During the winter of 1944, he directed his efforts toward PbS in an attempt to achieve reliable characteristics for longer wavelength cells. It soon became apparent that PbS offered the greatest potential of all the sulfide cells he had investigated up to this point. In addition, he realized that a greater photosensitivity could be achieved by evaporating PbS cells in the presence of oxygen. By December of 1944, Cashman was able to develop PbS films by chemical deposition methods. He soon acquired several captured German PbS cells which he determined were superior to his due to their smaller size. As a result, he decided to fabricate smaller cells which he soon found to exhibit relatively excellent performance (ref. 3).

Post World War II Development

Immediately following World War II, the interest in research of lead salt detectors initially received less military emphasis. Work was done by Photoswitch, Inc. to achieve more reliable methods to chemically prepare and sensitize PbS films. The fundamental characteristics of PbS layers, as well as developing mosaic tubes, were of primary concern. However, military demands soon surfaced once again as the Eastman Kodak Company began research in 1947 for the U.S. Navy in developing a PbS detector for the air-to-air Dove missile. Upon successful demonstration that the infrared seeker could generate signals in response to detecting a 100° C target, the U.S. Navy awarded a contract to Eastman Kodak to develop PbS photoconductive cells (ref. 3). By developing the PbS cells for the Dove missile, the first application for a terminally guided missile had been accomplished. Subsequently, Eastman Kodak secretly developed a deposition process for sensitizing PbS films that did not require further baking or oxidation. With much research being previously devoted to the study of PbS, Henry Levinstein of Syracuse University, decided to investigate the photoconductive effects of PbSe and lead telluride (PbTe). With support from the military, Levinstein directed his graduate students at Syracuse University to research the preparation of thin films of PbSe and PbTe (ref. 3). Syracuse University thus became a significant source of infrared photoconductive devices in the United States. However, it is somewhat interesting to note that much of the effort was focused simply on the photoconductive behavior of PbSe and PbTe crystals and not on military or commercial applications.

In an attempt to gain as much information as possible about the photoconductive behavior of lead salts, the Naval Ordnance Laboratory (NOL) assembled a committee in 1948 to review the studies made by various scientists in the area of infrared technology, both locally and abroad. Wayne W. Scanlon of NOL soon revealed that British reports on the studies indicated that the spectral response of PbTe was limited to about 3.5 μm (ref. 3). In addition, it was found that PbTe cells were insensitive when exposed to air at room temperature. Thus, a decision was made not to spend prolific amounts of time on the study of PbTe for military applications. Scanlon soon conducted experiments to gain a better understanding of the forbidden energy band gap, electron-hole mobility, and sensitivity of both lead salt detectors. Within a decade, NOL scientists felt they had developed a thorough understanding of the photoconductive behavior of lead salt detectors. As a consequence of the benefits received by the combined efforts of many scientists, symposiums were sponsored by the Infrared Information Symposia (IRIS) to exchange information on the research of lead salt detectors. Although many scientists initially doubted the success of such a forum, the positive effects soon became apparent and were well received. Thus, symposiums offered a platform by which the development of lead salt detectors could then be monitored on a world wide basis.

Current Development Efforts

Despite the fact that a great deal of the effort into understanding the behavior of lead salt detectors was accomplished over 40 years ago, there still exists some research and development at the present time. Presently, some of the effort is concentrated into developing more sensitive and reliable detectors, as well as applying them to meet military and commercial demands. In general, most analysts say that the United States military constitutes as much as three-fourths of the total infrared detector market. In an effort to keep up with the demand, chemical deposition and detector delineation methods are constantly being refined so that large quantities of highly reliable and sensitive detectors can be fabricated with success. In addition, large multi-element detector arrays, similar to one shown in figure 3, have since become the industry standard with respect to detector configurations. However, the level of research activity has declined significantly since the early 1980s, with a minor effort now being devoted to lead salt detectors. Most of the current research pertaining to photoconductive infrared detectors today has primarily involved more expensive mercury cadmium telluride (HgCdTe) devices.

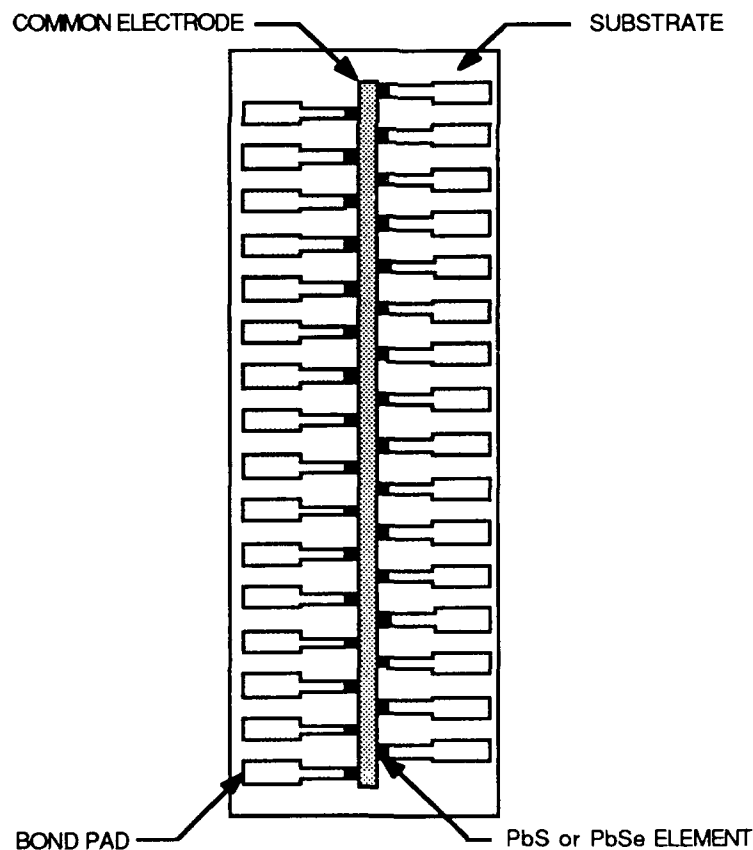


Figure 3. Planar view of a 32 element linear detector array

THEORETICAL BACKGROUND

As previously mentioned, the operation of a photoconductive lead salt detector relies heavily on the transfer of infrared energy from incoming photons to electrons residing within the detector material. This transfer results in an electronic reorganization within the atomic structure of the semiconductor. In the case of an intrinsic semiconductor such as PbS or PbSe, energy transferred from a photon striking the surface raises an electron from a non-conducting to a conducting state. This action, along with the influence of temperature, results in the production of an electron-hole pair containing both a positive and a negative charge carrier. If the detector is biased in a manner similar to that shown in figure 4, an electric field is developed which will increase the number of charge carriers. This phenomenon, known as the photoconductive effect, thus reduces the resistance of the device. Consequently, this will result in an increase in the amount of current flowing through the device. The measured output signal can be either the change in current through the detector or the change in voltage developed across the load resistor in series with the detector. In most cases, the signal detected is the change in voltage developed across the load resistance which is matched to the dark resistance of the detector.

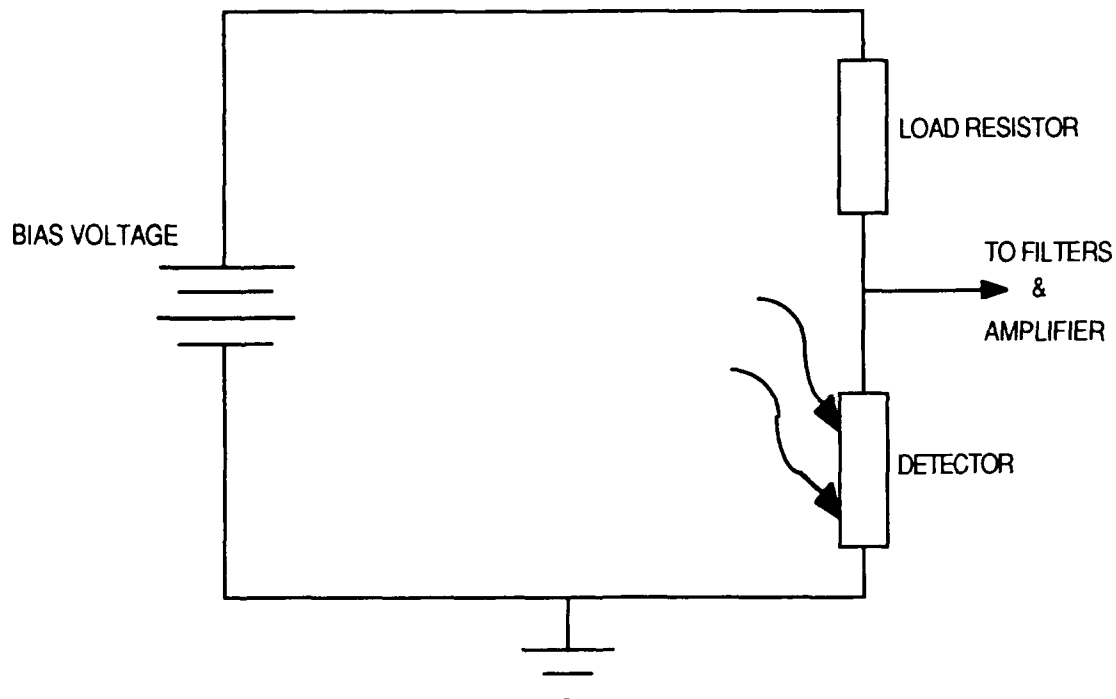


Figure 4. Photoconductive Detector Bias Circuit

The photoconductive process associated with the operation of lead salt detectors relies heavily on the internal photoeffects of the semiconductor material from which the detector is fabricated. In the instance of PbS and PbSe detectors, the primary mechanism responsible for the photoconductive process is the photoconductive effect. This phenomenon is largely influenced by the distribution of energy among the electrons within the semiconductor, as well as the temperature at which the detector operates. Therefore, in an attempt to better comprehend how a lead salt device detects infrared radiation, it becomes necessary to first gain an understanding of the electronic structure of solids. Of importance is the influence of the width of the forbidden energy band gap on the electrical conductivity of the detector. In addition, another important phenomenon is the effect of thermally induced charge carrier flow on the overall operation and performance of the device.

Electronic Structure of Solids

Electrons move about within a crystalline solid, with the motion of each electron described by a unique set of four quantum numbers. The first three quantum numbers describe the three components of momentum, while the fourth quantum number describes the orientation of the spin of the electron. The first three quantum numbers describing the motion are restricted to discrete closely consecutive values. Since the total energy associated with each electron is a function of these quantum numbers, it too can only assume discrete levels, also referred to as energy bands. These energy bands are sometimes separated from one another by as little as 10^{-14} electronvolts (eV)s. An electronvolt is the amount of kinetic energy acquired by an electron as it is accelerated through an electrical potential difference of 1 volt.

According to the Pauli Exclusion Principle for an isolated atomic system, no two electrons surrounding the nucleus of an atom in a solid can assume the same four quantum numbers when describing their motion. Thus, for every set of permissible four quantum numbers there is a value of energy which the electron must have. Therefore, when an electron occupies an energy band, it has a motion which is described by the only four quantum numbers that correspond to that energy value (ref. 5).

Under conditions where the atom is not excited or subjected to low temperatures near absolute zero, the motion of electrons results in the lowest energy bands being occupied. However, as a result of the Pauli Exclusion Principle, only a few electrons can move and occupy these lowest energy bands. The other electrons within the solid are required to move at higher energies as long as the lower energy bands are occupied in accordance with the Pauli Exclusion Principle (ref. 5). The highest of these energy bands that is completely filled is known as the valance band. The next higher occupied or unoccupied band is the conduction band. Separating the valence and conduction band is the forbidden energy band gap, E_g . This forbidden energy

band serves to act as a barrier to the flow of electrons from the valence to the conduction band since it does not permit the presence of an electron within the gap itself. This simply means that there exists no combination of four quantum numbers that correspond to electron energies in the gap range. Consequently, the width of the forbidden energy band is a major influence on the electrical behavior of the solid, since only electrons which appear in the conduction band can contribute to its electrical conductivity.

All solids are categorized as being either conductors, insulators, or semiconductors. Solids which have filled valence bands and partially filled conduction bands are considered to be good electrical conductors. The forbidden energy band gap in a conductor is usually so narrow that valence electrons are easily raised to the conduction band with or without any additional energy. The energy band gap for conductors is usually less than 0.1 eV. A typical energy band structure for an electrical conductor is shown below in figure 5.

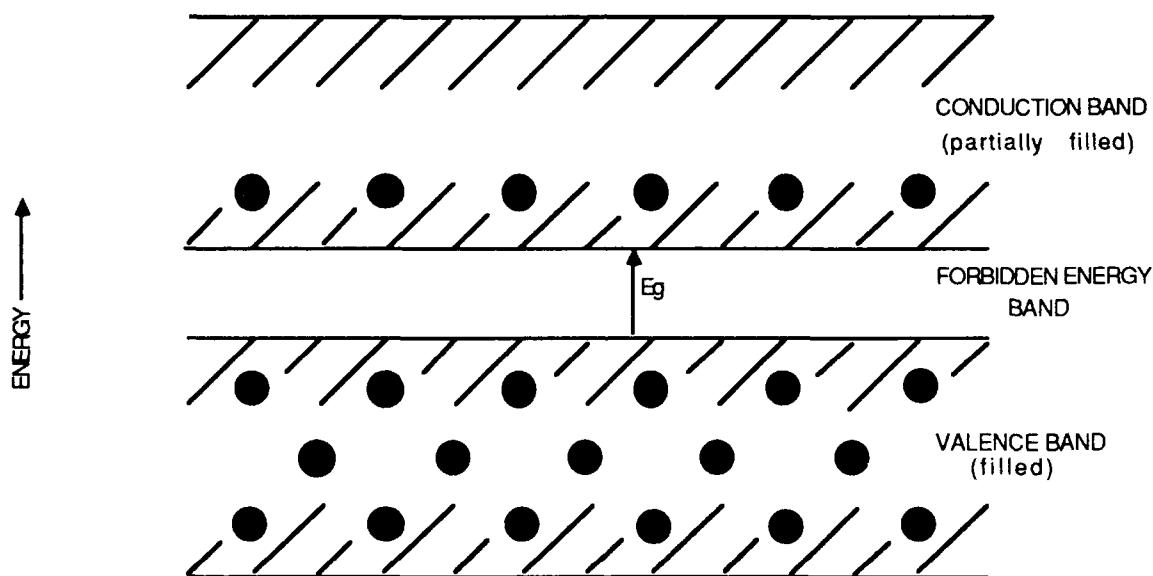


Figure 5. Energy bands in an electrical conductor.

Those solids which have filled valence bands, but no electrons in the conduction band, are good insulators. For a given insulator, the forbidden energy band gap is wide enough so that it becomes unlikely that a valence electron will acquire enough energy to elevate it to the conduction band. In most instances, the energy gap may be 3 eV or wider (ref. 6). A typical energy band structure for an electrical insulator is shown in figure 6 on page 11.

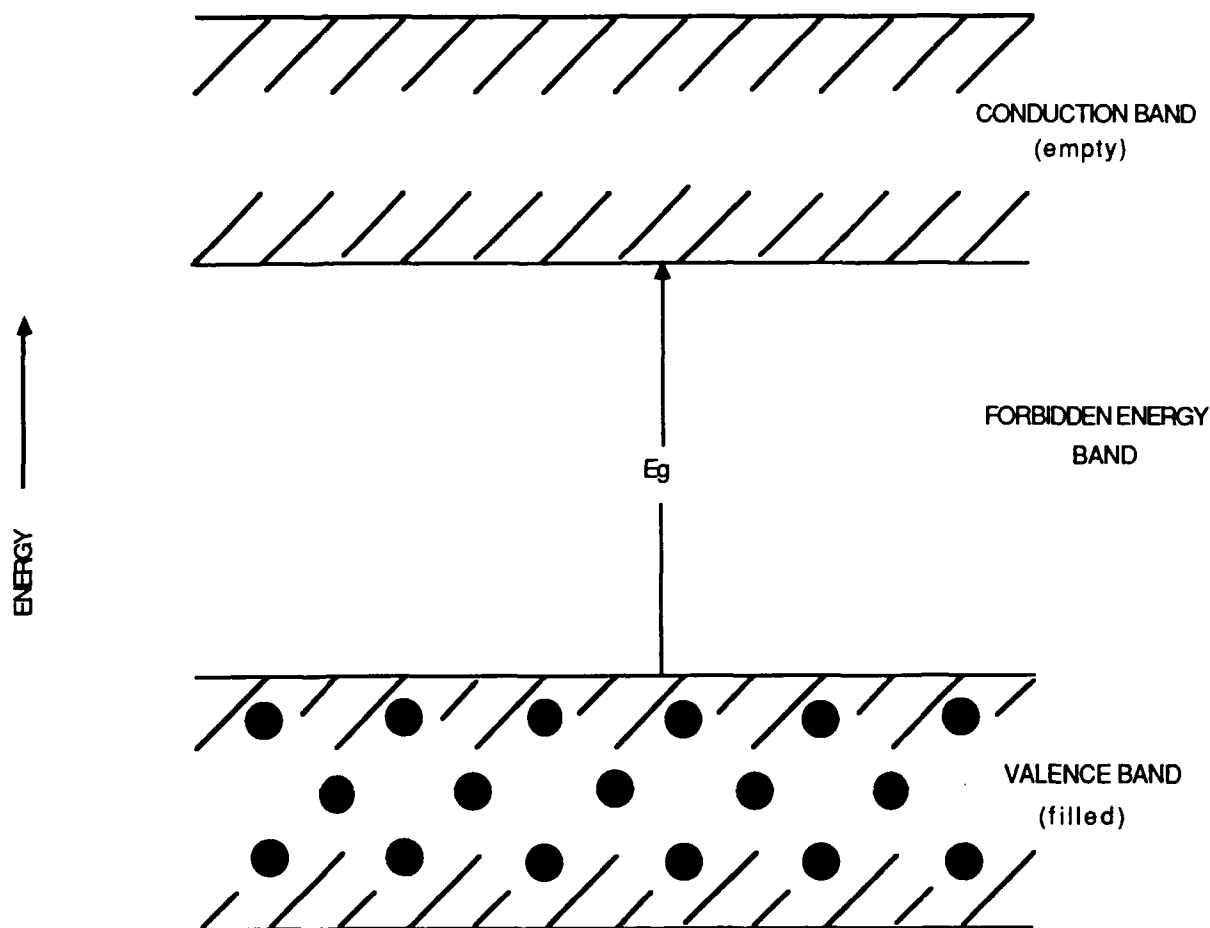


Figure 6. Energy bands in an electrical insulator.

In the case of a solid being a semiconductor, the forbidden energy band gap is narrow enough so that electrons can jump across the gap from the valence to the conduction band if they are excited by some form of energy. Figure 7 depicts the energy band structure for an intrinsic semiconductor. During those instances when the solid is subjected to low temperatures and no incident radiation, all of the electrons reside within the valence band. However, once sufficient energy is imparted to the valence band electrons to "kick" them over the gap, conduction occurs. Semiconductors that rely on the energy difference of the band gap for their operation are called intrinsic semiconductors. Extrinsic semiconductors are the result of deliberately doping the material with impurity electrons resulting in additional energy levels. Since PbS and PbSe are intrinsic semiconductor infrared detectors, further discussions concerning extrinsic semiconductor infrared detectors will not be discussed in this report.

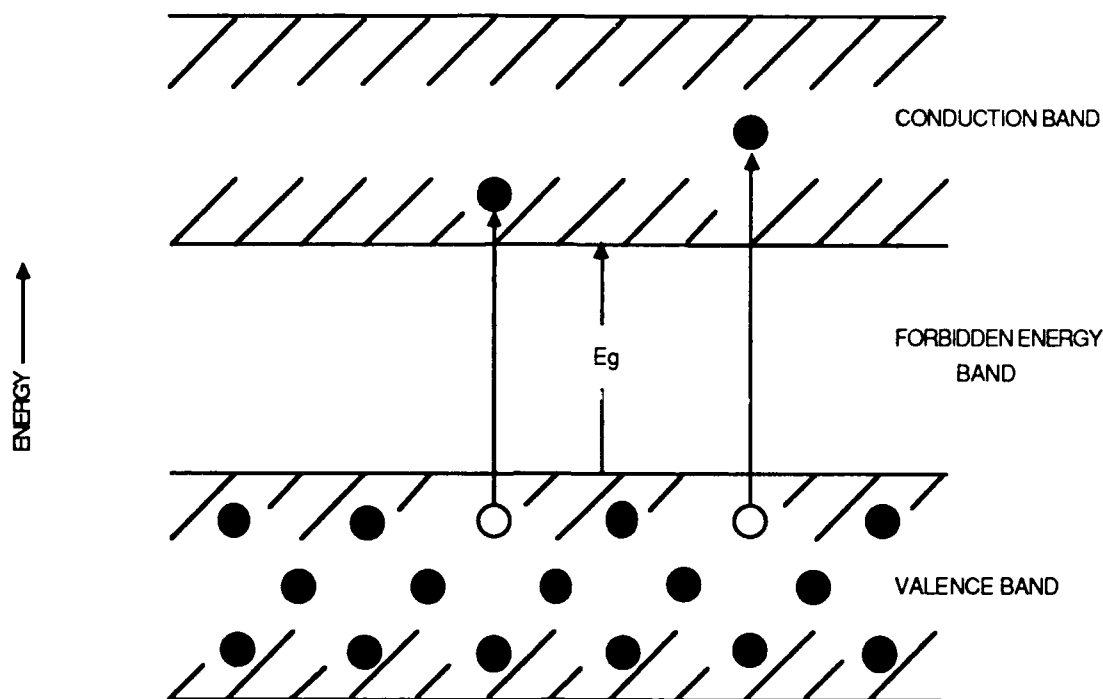


Figure 7. Energy bands in an intrinsic semiconductor

Thermally Excited Carrier Flow

The smooth motion of electrons traveling within a crystal lattice is heavily influenced by the perfect spatial periodicity of the electrical potential energy (ref. 5). If there should exist some boundary within the lattice upon which the spatial periodicity is altered, a disruption in the smooth motion of the electrons is likely to occur. Atoms in agitated thermal motion, even at low temperatures approaching 77°K, tend to interfere with the periodicity of the lattice. This, in turn, could also disrupt the smooth motion of electrons traveling within the lattice. However, any change in the smooth motion of these electrons will occur only to those electrons which can alter their quantum numbers by such amounts that the change in electron energy is equal to the energy to be transferred by collision with the displaced atoms (ref. 5). However, the Pauli Exclusion Principle prohibits the absorption of such energy by an electron if the resulting transition would bring this electron to an energy level that was previously occupied. Surprisingly, however, there still exists a finite probability that the energy exchange between the electrons and the lattice atoms is great enough to cause top level valence electrons to acquire energies near the bottom of the conduction band if such vacancies do indeed exist. If such conduction band motion is achieved, the conduction band electron is free to acquire relatively small amounts of additional energy from

the lattice atoms provided there exist vacancies within the conduction band. The ramification of this phenomenon is that a signal is generated by the detector in response to this type of electron flow. This signal is noise that will corrupt the fidelity of the true detector response to incident infrared radiation. It is for this reason that various cooling techniques are employed to counteract the detrimental effects of thermally excited carrier flow in lead salt detectors

Photoconductivity

The mechanism which most governs the electrical behavior of photoconductive detectors is known as the photoconductive effect. This phenomenon basically involves a change in the electrical conductivity of a solid material when illuminated by varying amounts of radiation. In the case of a lead salt detector, the photoconductive effect is initiated by incident infrared radiation, in the form of photons, striking valence electrons within the detector material. If the energy of each incident photon is at least as great as the band gap energy of the intrinsic semiconductor, then valence electrons which have been struck can acquire sufficient energy to jump across the band gap to the conduction band (ref. 7). Thus, the primary requirement for photoconductivity is:

$$h\nu \geq E_g, \quad (1)$$

or

$$\frac{hc}{\lambda} \geq E_g \quad (2)$$

where

- h = Plank's constant = 6.6256×10^{-34} J sec
- ν = frequency of the incident photons (sec^{-1})
- c = speed of light = 3×10^{14} $\mu\text{m sec}^{-1}$
- λ = wavelength of the incident photons (μm)
- E_g = band gap energy (J).

Once photoconductivity is initiated, the locations formerly occupied by the electrons in the valence band are referred to as holes, and are considered to be positively charged. In order to increase the responsivity of the detector, a photoconductive current gain must be established. This is accomplished by biasing the detector so that an electric field is set up across the semiconductor. As indicated in figure 8, the presence of this electric field causes holes to flow through the material just as electrons do, al-

though the two particle types flow in opposite directions (ref. 6). Therefore, biasing the detector helps generate a photocurrent proportional to the photoexcited electron concentration. Hence, in an intrinsic semiconductor the excitation of a valence electron into the conduction band, and the biasing of the device, help create an electron-hole pair of charge carriers which both contribute to the conductivity of the device.

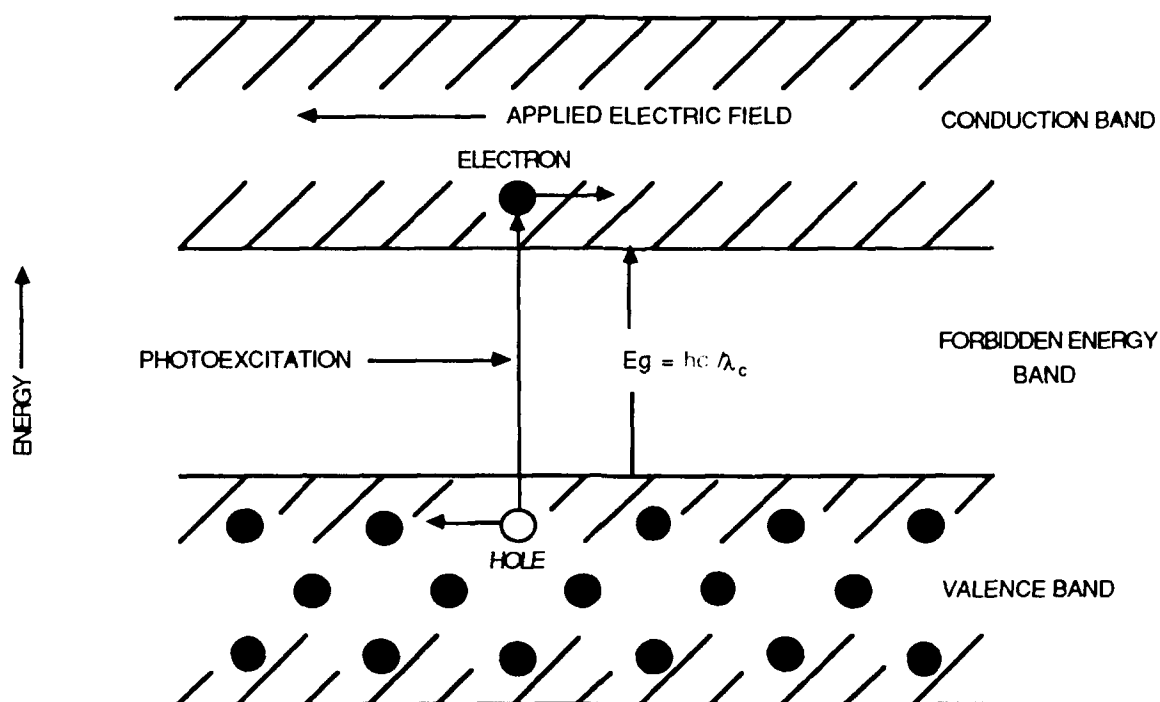


Figure 8. Photoexcitation process in an intrinsic semiconductor

However, there exists a wavelength upon which valence electrons can no longer acquire sufficient energy to promote the production of electron-hole pairs. This cutoff wavelength can be determined by rearranging equation 2 to yield the equation:

$$\lambda_c (\mu\text{m}) = \frac{hc}{E_g (\text{eV})} \cong \frac{1.24 \text{ eV } \mu\text{m}}{E_g (\text{eV})} \quad (3)$$

The cutoff wavelength establishes the upper limit on the region of operation that a particular infrared detector is capable of detecting. Thus, for a PbS detector with an energy band gap of $E_g = 0.42 \text{ eV}$ at 295° K , the cutoff wavelength is $\lambda_c = 2.9 \mu\text{m}$. Similarly, for a PbSe detector with an energy band gap of $E_g = 0.23 \text{ eV}$ at 195° K , the cutoff wavelength is $\lambda_c = 5.4 \mu\text{m}$ (ref. 7).

SYSTEM DESCRIPTION

Infrared detection systems are usually designed to either detect the presence of a moving or stationary target, track it as it moves, or to simply gain information about its identity. A basic block diagram of the elements which comprise a typical infrared system is shown below in figure 9. Although there are often variations between systems concerning the implementation of several of these system elements, the framework for the detection process basically follows the same methodology depicted below. The major variations in implementation which do occur between infrared systems obviously depend on the particular application and the complexity of the design. The most common areas where such differences are likely to occur usually pertain to the choice of detector, detector coolers, signal processing and the display or control portions of the system. However, the implementation of every element of the infrared system block diagram can vary for every application. Despite these variations, however, the overall organization of most infrared systems is similar to that shown below.

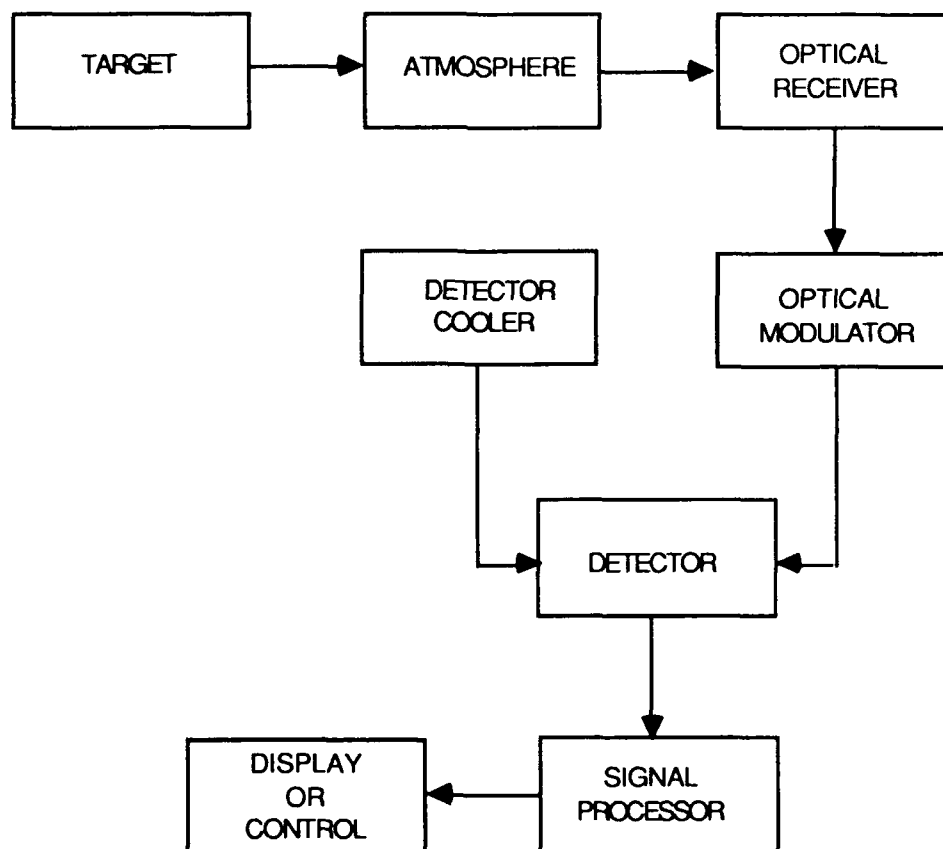


Figure 9. Block diagram of the elements of an infrared system (ref. 6).

The operation of the system focuses on the emission of infrared radiation from a target of interest residing in an environment containing some degree of background clutter. Since the energy radiated from the target must pass through some portion of the earth's atmosphere, it will be attenuated due to the effects of air pressure, temperature, water vapor and the density of gaseous obscurants. Prior to reaching the detector, the radiant flux from a target will be scattered by various particles along its line of sight, absorbed by water vapor and other molecules and modulated by rapid variations within the atmosphere (ref. 6). With regard to the three sources of attenuation, the absorption of infrared radiation poses the greatest problem to the transmission of energy through the earth's atmosphere. Figure 10 indicates the spectral transmittance of the atmosphere measured over a 6000 ft horizontal path at sea level. The various molecules responsible for the absorption bands are given at the bottom of this figure. Those regions indicating high transmittance over the infrared spectrum are referred to as atmospheric windows. As figure 10 indicates, one important window exists from approximately 0.2 μm to 2.5 μm and another from approximately 3.0 μm to 5.0 μm . It is these two atmospheric windows that lead salt detectors attempt to exploit. Thus, as previously mentioned, PbS detectors are designed to respond to radiation in the 1.0 μm to 3.0 μm region of the electromagnetic spectrum, while PbSe detectors respond in the 1.0 μm to 7.0 μm region.

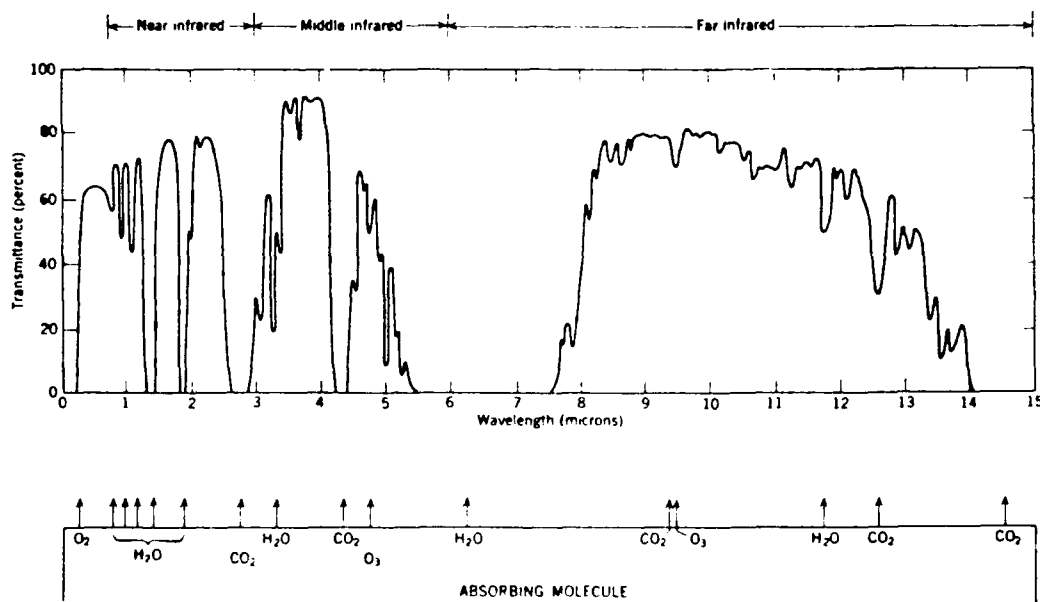


Figure 10. Transmittance of infrared radiation through the atmosphere (ref. 6)

In order to capture this radiant energy, an infrared transducer is utilized. The transducer is responsible for gathering this energy and forwarding it to the detector. The transducer is usually comprised of an optical receiver or telescope, detector with electronics and some type of detector cooler. The optical receiver, which is analogous to a radar antenna, predominantly consists of an optical lens, a spectral filter and a mirror. There are many configurations for an optical receiver subsystem. However, most systems initially employ a mirror to gather and direct the incoming radiation through an optical lens, filter out the unwanted spectral components and finally funnel the energy onto the surface of the detector. In some designs, the lens is coated on one surface with a thin film of silicon. In this instance, the surface tends to possess some of the properties of a mirror, thus eliminating the need for a mirror itself. For infrared detectors that stare at a scene, an optical modulator is occasionally incorporated either before the mirror or after the filter to provide angular information about a target or suppress unwanted signals from backgrounds (ref. 8). This is accomplished by placing a center spun reticle or chopper wheel somewhere between the path of incoming radiation and the detector. As the radiated energy passes through the reticle and onto the detector, a response is generated to variations in temperature between the scene and the reticle. If half of the reticle is opaque and the other half is clear, and if there exists some means of determining the phase relationship between the reticle and the detector, then angular information about the position of the target image on the reticle plane can be determined by examining the phase of the detector signal (ref. 8).

The second important subsystem of the infrared transducer is the detector and its electronics. The detector can either be a single element photocell or some type of multi-element array. The infrared detector converts the filtered radiation from the optical receiver subsystem into an electrical signal. The output signal of the detector is comprised of infrared energy radiated from both the target and background clutter as well as detector noise. Therefore, signal conditioning electronics are incorporated to amplify and filter the detector response prior to reaching the signal processor. In addition, electronic circuits also contain analog-to-digital converters and memory. In some implementations, this circuitry is generally considered part of the signal processing subsystem. In many instances, the detector and electronics are located on the same circuit board in an effort to reduce cost, complexity and size. Such an implementation is more commonly referred to as either a Focal Plane Assembly or Focal Plane Array (FPA).

The third important subsystem of the infrared transducer is the detector cooler. Cooling infrared detectors is generally regarded as the best method to enhance their overall performance. In order to increase the responsivity, D^* (pronounced dee-star), and dark resistance at longer wavelengths, the semiconductor materials used to fabricate the detectors must possess narrow forbidden energy band gaps. However, semiconductors which possess such small gaps would inherently allow the passage of

large numbers of thermally induced charge carriers. Consequently, since a higher responsivity would require a minimization in the number of free carriers, the best way to reduce carrier flow would be to cool the detector. Most lead salt detectors are designed to operate at three different temperatures; Ambient Temperature Operation (ATO) at 295°K, Intermediate Temperature Operation (ITO) at 193°K and Low Temperature Operation (LTO) at 77°K. These three temperatures correspond to room temperature, the boiling point of freon 13 and the boiling point of liquid nitrogen, respectively (ref. 9). The choice of which temperature to operate at depends on the application and the desired spectral response of the detector. Although, several methods are used to cool detectors, the two most common techniques that are employed today are dewars and thermoelectric (TE) coolers. Dewars can be used for detectors operating as low as the LTO regime, while TE coolers can only be used down to the ITO region.

The signal processing portion of an infrared detection system is usually comprised of a processor semiconductor device, memory and signal conditioning electronics. The signal processor essentially extracts target and scene information from the signals stored in memory devices located within the signal conditioning circuitry. The processor then forwards this information to either a display or some control device such as a microprocessor. It is this final element of the system which ultimately is responsible for either displaying visually what the detector has sensed electromagnetically or determining whether the detector has identified a target of interest.

CONCLUSIONS

Lead sulfide (PbS) and lead selenide (PbSe) detectors are thin film semiconductor devices which are employed to respond to infrared radiation in the 1 μm to 3 μm and 1 μm to 7 μm regions of the electromagnetic spectrum, respectively. These two detectors are members of the lead salt family of photoconductive detectors, with much of their development occurring as a result of their exploitation for military applications primarily during World War II. In the case of both detectors, incident photons in the infrared region bombard the surface of the thin film semiconductor and collide with electrons residing within the valence band of the detector material. This interaction stimulates the generation of electron-hole pairs, resulting in an increase in the amount of current flowing through the device. Of importance is the influence of the width of the forbidden energy band gap on the electrical conductivity of the detector. In addition, another important phenomenon is the effect of thermally induced charge carrier flow on the overall operation and performance of the device. The output signal of the detector circuit is either a change in detector current or a change in voltage developed across a load resistor. Thus, when the device is incorporated as part of a sensor system, it is these current or voltage changes which are interpreted by the detector circuit processor as being the target of interest or not.

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